

First Searches for Single Top Quark Production with ATLAS

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for the ATLAS collaboration

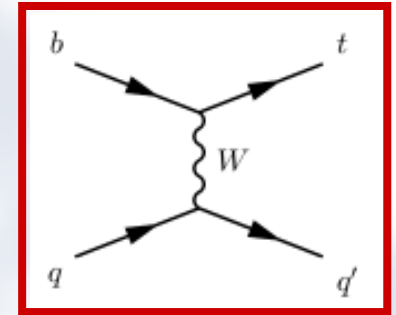
DIS2011 @ JLab
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Single Top at the LHC

Three production modes with different rates and phenomenologies:

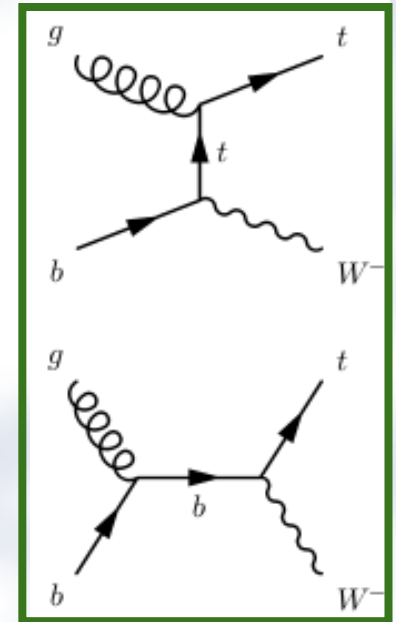
- **t-channel ($\sigma = 66 \text{ pb}$)**

- Largest production rate
- Charge asymmetric at the LHC
- Final state: 1 lepton + 2 jets (1 b, 1 light) + E_T^{miss}
- Backgrounds: Top pairs, W/Z+jets, WW, WZ, ZZ, multijets



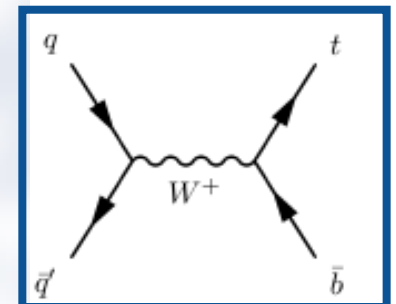
- **Wt-channel ($\sigma = 15 \text{ pb}$)**

- Now accessible at the LHC
- Lepton+jets: 1 lepton + 3 jets (1 b, 2 light) + E_T^{miss}
 - Backgrounds: Top pairs, W/Z+jets, WW, WZ, ZZ, multijets
- Dilepton: 2 leptons + 1 b-jet + E_T^{miss}
 - Backgrounds: Top pairs, Z+jets, WW, WZ, ZZ



- **s-channel ($\sigma = 4 \text{ pb}$)**

- Small production rate at the LHC
- Impossible with current amount of data



Single Top Program at ATLAS

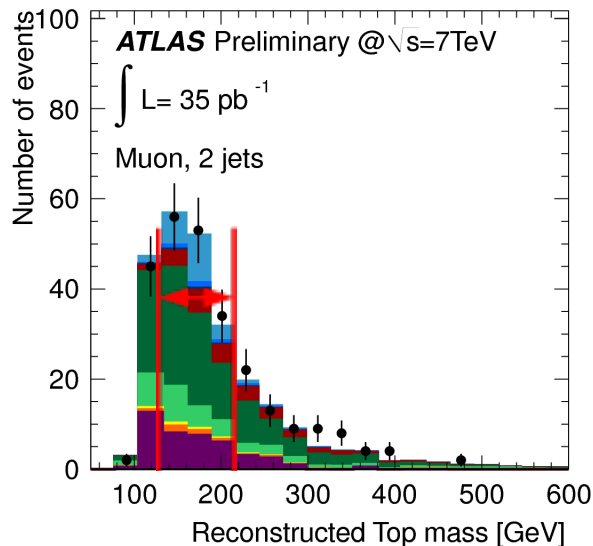
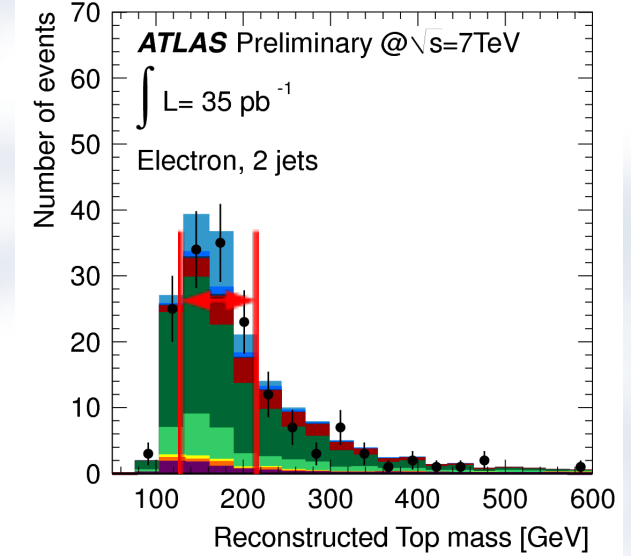
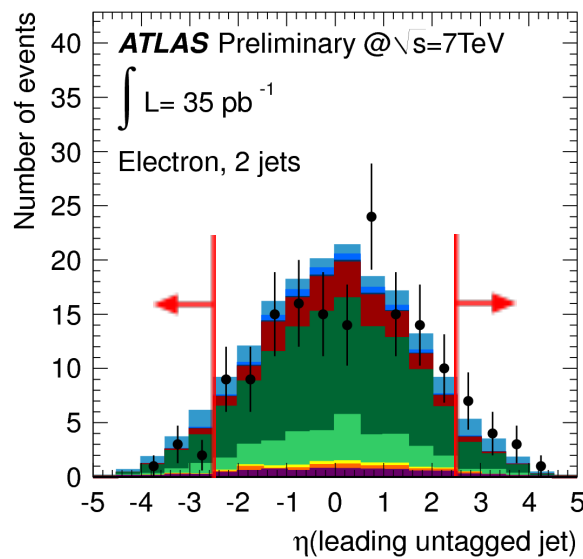
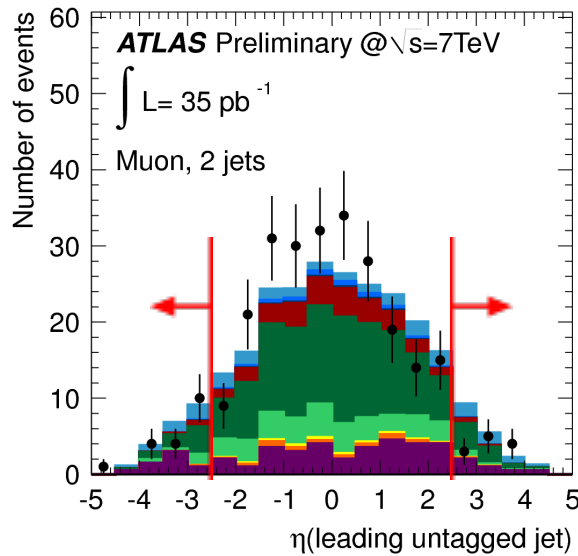
- First priority: work toward (re-)discovery, with focus on **understanding backgrounds** ← TODAY
 - Use 7 TeV LHC (pp) data collected June-October 2010, total integrated luminosity = 35 pb^{-1}
 - Search for t-channel single top quark production
 - Cut-based analysis
 - Likelihood analysis
 - Search for Wt-channel single top quark production
 - Lepton+jets final states
 - Dilepton final states
 - Reference: [ATLAS-CONF-2011-027](#)
- Long-term:
 - Precisely measure the cross-sections for all three processes
 - Constrain BSM models (4th gen., W', charged Higgs, FCNC)

Lepton+jets Preselection / BG

- Require:
 - 1 isolated electron or muon with $E_T(p_T) > 20$ GeV
 - 2, 3, or 4 jets with $p_T > 25$ GeV, exactly one b-tagged
 - Use sec. vertex tagging algorithm, eff=50%, light rej~270
 - $E_T^{\text{miss}} > 25$ GeV
 - $M_T > 60$ GeV - E_T^{miss} (multijet veto)
- Main backgrounds are determined from data
 - Multijets:
 - Binned likelihood fit of E_T^{miss} distribution
 - Matrix method
 - W+jets:
 - Overall normalization from pretag
 - Composition from pretag/tag constraints
- Other backgrounds (top pair, Z+jets, WW, WZ, ZZ) from MC

t-channel Analyses ~ Cut-based

Require exactly **2** jets, $|\eta(\text{ujet})| > 2.5$, $130 < m_{\text{top}} < 210$ GeV:

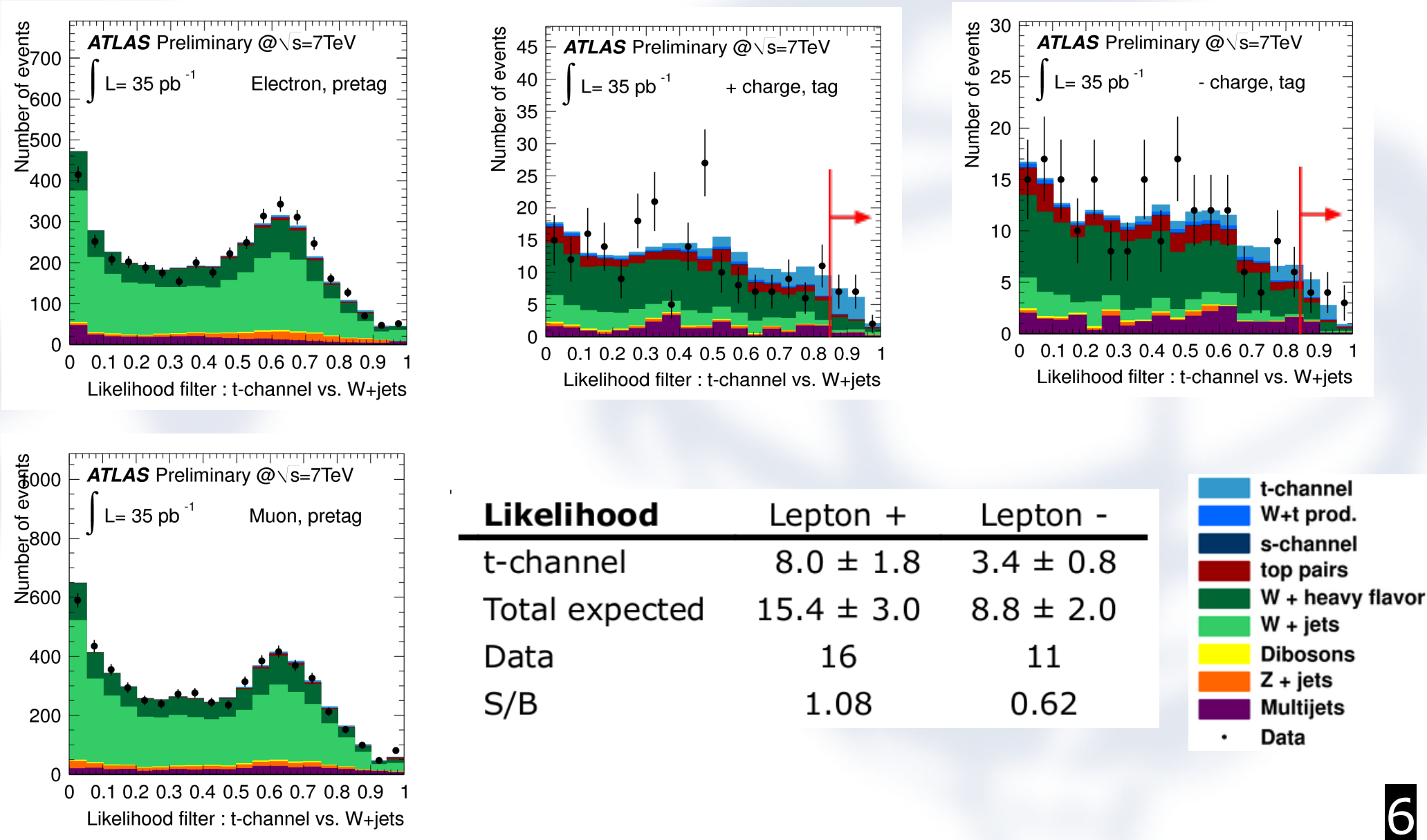


Cut-based	Lepton +	Lepton -
t-channel	10.3 ± 1.8	4.4 ± 0.8
Total expected	22.7 ± 3.8	13.2 ± 2.8
Data	21	11
S/B	0.83	0.50



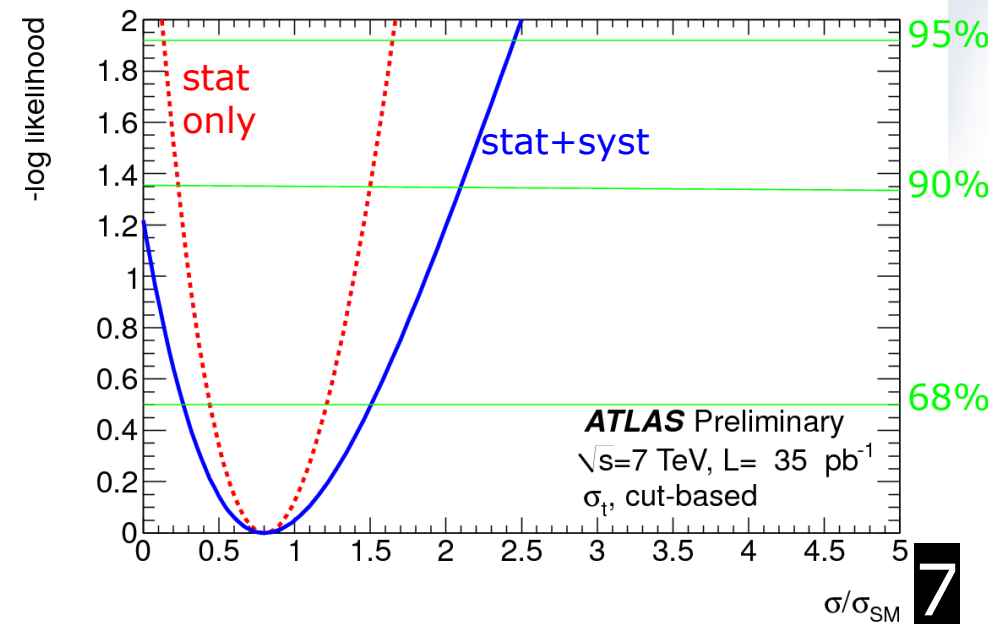
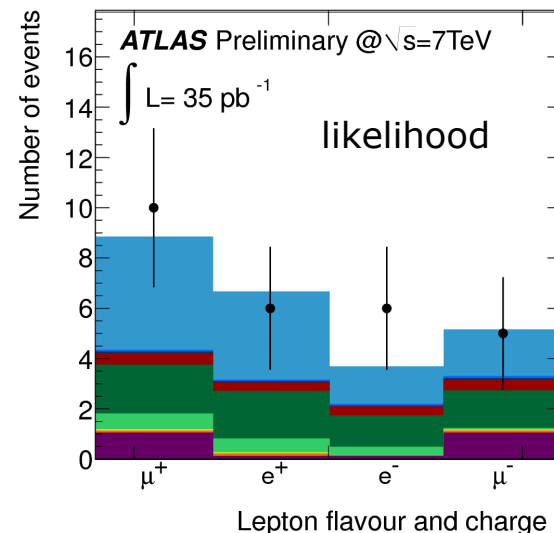
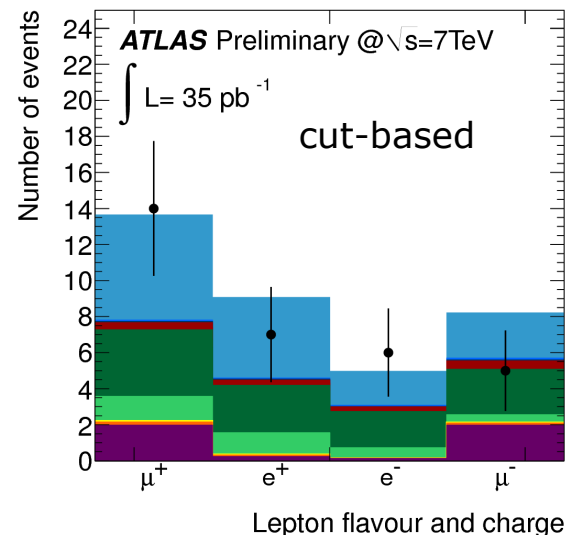
t-channel Analyses ~ Likelihood

Build a 5-variable likelihood:



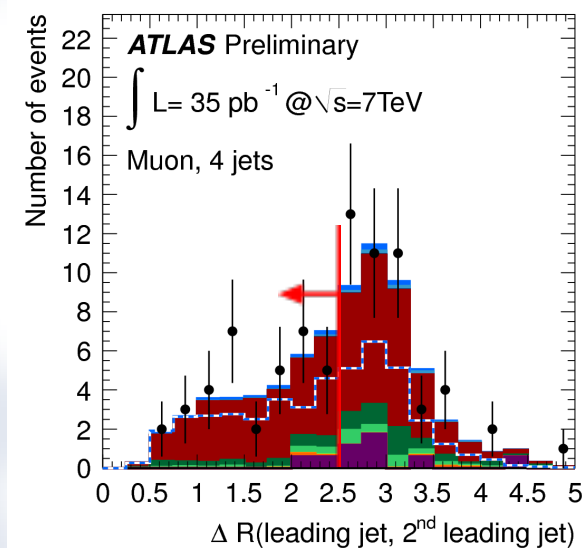
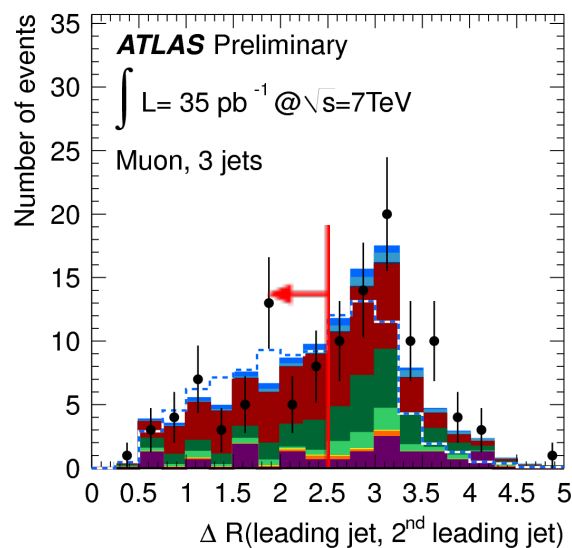
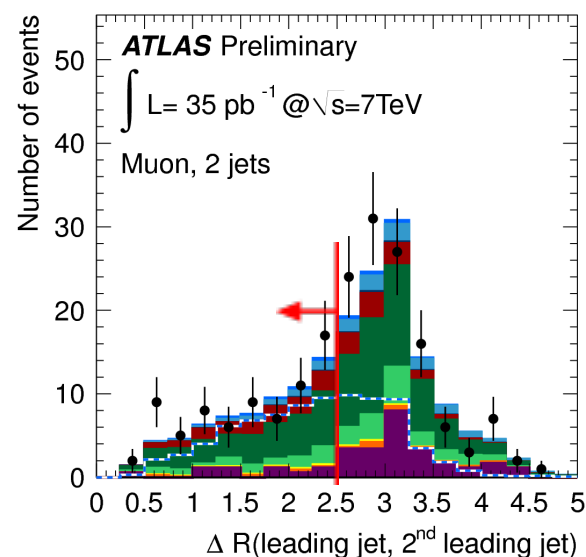
t-channel Results

- Combine $e+\mu$, then separate into $+/-$ charge samples to improve sensitivity
- Performance of the cut-based and likelihood analyses is very similar, use cut-based as baseline
- Cross-section/limit extraction based on profile likelihood ratio
- Find $\sigma_t = 53^{+27}_{-24} \text{ (stat)}^{+38}_{-27} \text{ (syst)} \text{ pb}$ [1.6σ obs 1.9σ exp]
 - Translates to $\sigma_t < 182 \text{ pb}$ @ 95% CL
 - Dominant uncertainties: jet energy scale, b-tagging, W+jets normalization



Wt-channel Lepton+jets Analysis

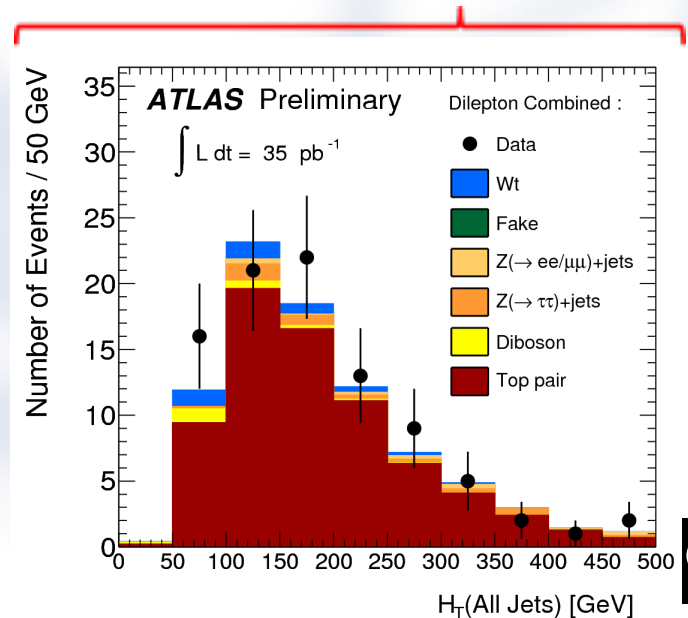
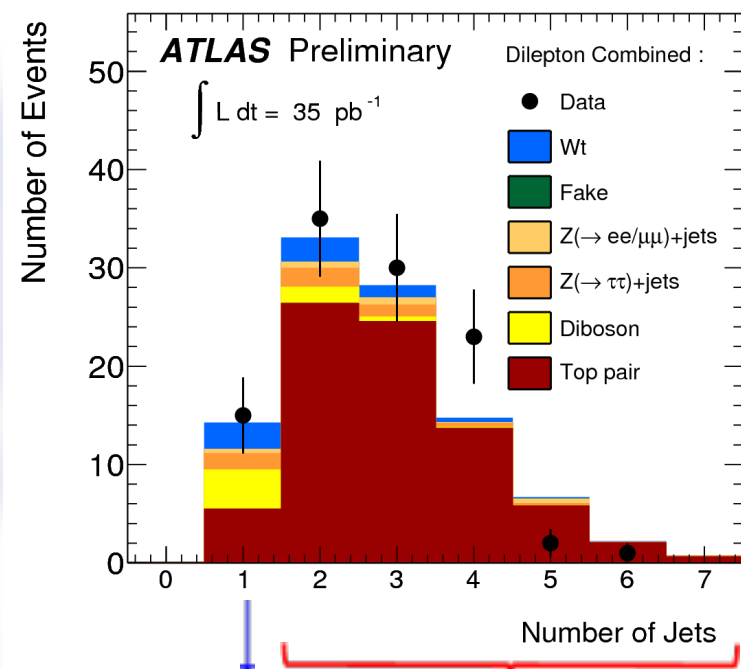
- Same preselection as t-channel analysis
- Additionally require:
 - 2-4 central ($|\eta| < 2.5$) jets, one b-tagged with $p_T > 35$ GeV
 - $\Delta R(j_1, j_2) < 2.5$
- Background composition varies greatly between different jet multiplicity bins
 - Customized selections will bring large improvement



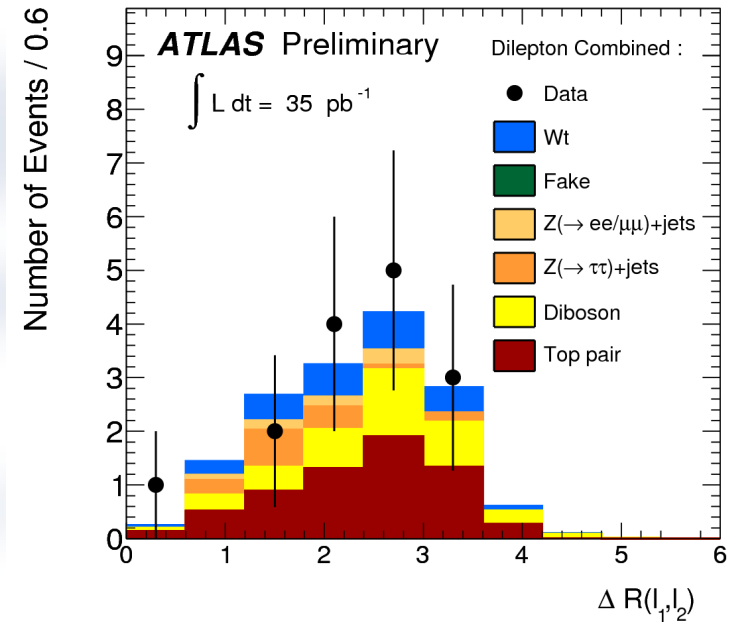
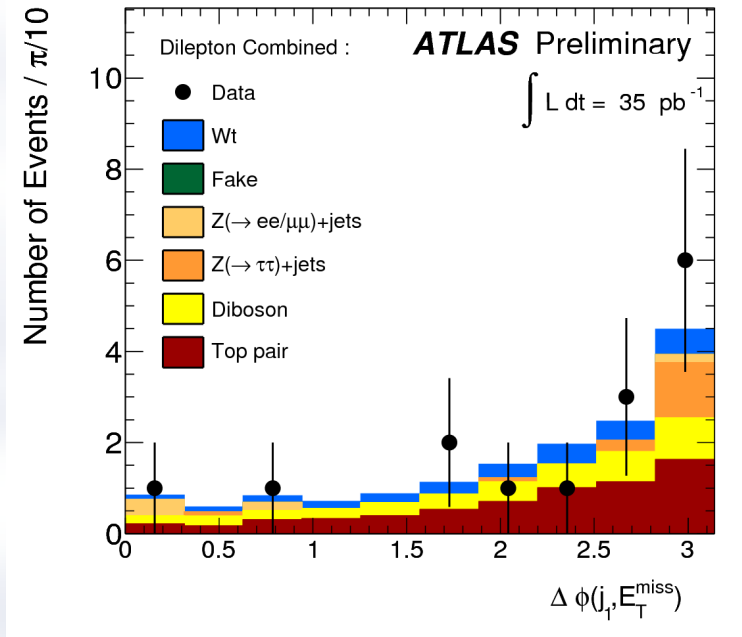
Muon	2 jets	3 jets	4 jets
Wt-channel	2.4 ± 0.5	2.8 ± 0.4	1.2 ± 0.2
Total expected	66.2 ± 14.6	50.5 ± 8.2	32.6 ± 4.4
Data	74	50	37
S/B	0.04	0.06	0.04

Wt-channel Dilepton Selection/BG

- Require:
 - 2 isolated, opp. charge electrons or muons ($ee/e\mu/\mu\mu$)
 - Exactly 1 jet with $p_T > 20$ GeV
 - $|M_{ll} - M_Z| > 10$ GeV and $E_T^{\text{miss}} > 50$ GeV ($ee/\mu\mu$)
 - $H_T(l_1, l_2, j_1, E_T^{\text{miss}}) > 160$ GeV ($e\mu$)
- Backgrounds from data and MC
 - Fakes (W+jets, multijet): 4x4 Matrix method
 - Drell-Yan: control + validation samples
 - Top pair (**main BG**): normalized in control sample
 - $Z \rightarrow \tau\tau$, WW, WZ, ZZ: MC predictions



Wt-channel Dilepton Analysis



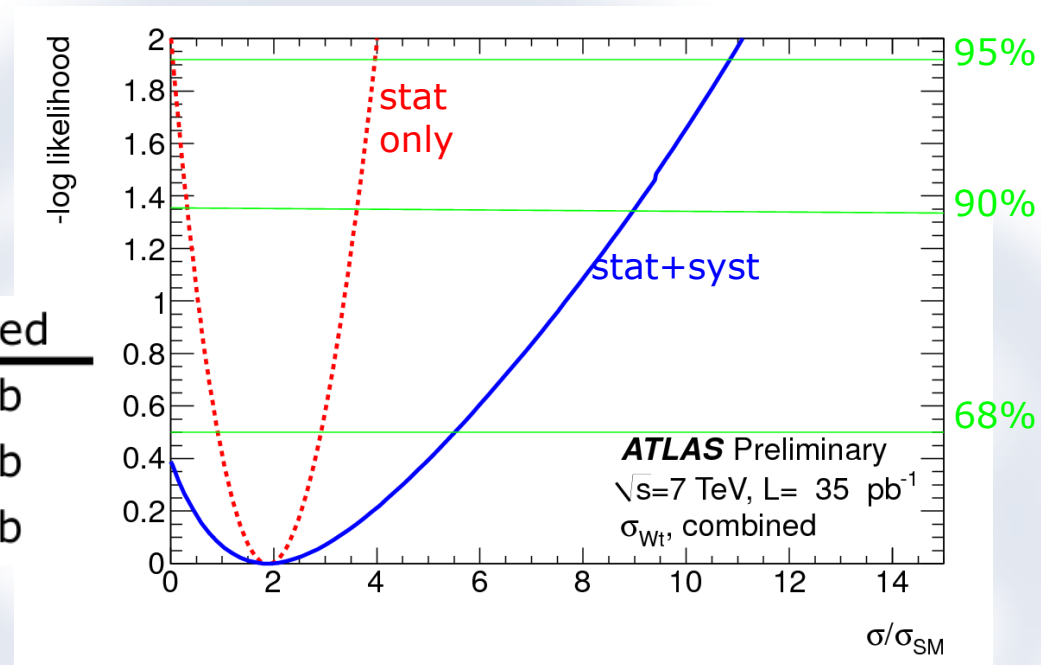
	$e\mu$	ee	$\mu\mu$
Wt-channel	1.7 ± 0.5	0.3 ± 0.1	0.8 ± 0.2
Total expected	9.2 ± 2.4	1.8 ± 0.6	4.5 ± 1.2
Data	12	1	2
S/B	0.23	0.20	0.22

Combined Wt -channel Result

Total of **9** orthogonal final states (e/ μ +2/3/4 jets, ee/e μ / $\mu\mu$ +1 jet)

- Set limits using profile likelihood ratio:

95% CL Upper Limit	Expected	Observed
Lepton+jets	123 pb	198 pb
Dilepton	112 pb	110 pb
Combined	94 pb	158 pb



- Expected (observed) limit on σ_{Wt} corresponds to 6.3 (10.5) times the SM expectation
- Dominant sources of uncertainty
 - Lepton+jets: jet energy scale, b-tagging
 - Dilepton: jet energy scale, initial/final state radiation modeling
 - Signal statistics also quite important for both analyses

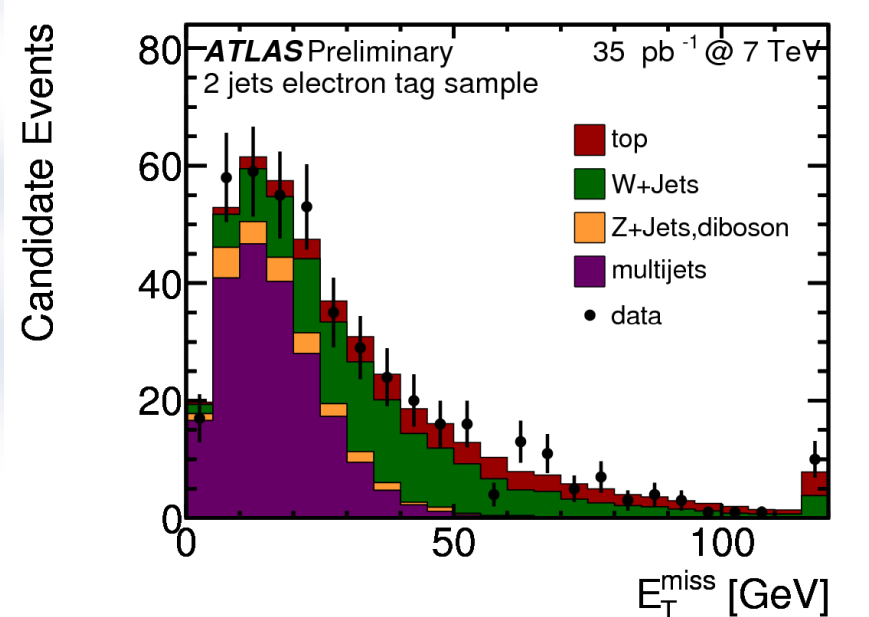
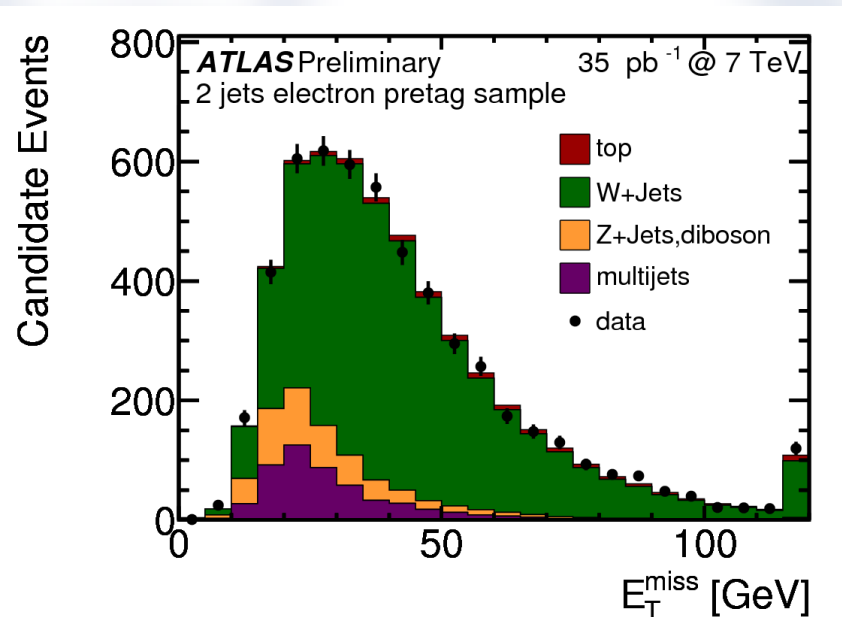
Summary And Outlook

- First searches for electroweak single top quark production in LHC collision data ($L = 35 \text{ pb}^{-1}$) with ATLAS
- **t-channel** searches use 2-jet events with 1 b-tagged jet
 - Simple cut-based approach ($m_{\text{top}}, |\eta(\text{untagged jet})|$)
 - 5-variable likelihood used as cross-check
 - Result significance is 1.6σ , compatible with SM
- First limit on the **Wt-channel** process
 - Lepton+jets analysis using events with 2-4 central jets
 - Dilepton analysis using 1-jet events
 - Observed (expected) limit is 10.5 (6.3) x SM cross-section
- Expect large improvements on both results with more data
 - LHC and ATLAS already back in running mode
 - Can explore more complex analysis techniques

~ BACKUP ~

Fake Background: Fitting method

- Perform a binned likelihood fit to the observed E_T^{miss} distribution
- Templates for 'real' lepton events are taken from MC
- 'Fake' lepton template obtained by replacing lepton requirement with a 'lepton-like jet' requirement



Fake Background: Matrix method

- Define two selection levels (**L**oose/**T**ight) for leptons
- Measure **r** and **f** = $N_{\text{tight}}/N_{\text{loose}}$ in control regions enriched with **r**eal and **f**ake leptons
 - Real: Events with 1 loose + 1 tight w/ M_{ll} near Z mass
 - Fake: Events with 1 loose, low E_T^{miss}
- Extract full sample composition by inverting a system of equations

- Lepton+jets:

$$N^{\text{loose}} = N_{\text{real}}^{\text{loose}} + N_{\text{fake}}^{\text{loose}}$$

$$N^{\text{tight}} = N_{\text{real}}^{\text{tight}} + N_{\text{fake}}^{\text{tight}} = \epsilon_{\text{real}} N_{\text{real}}^{\text{loose}} + \epsilon_{\text{fake}} N_{\text{fake}}^{\text{loose}}$$

- Dilepton:

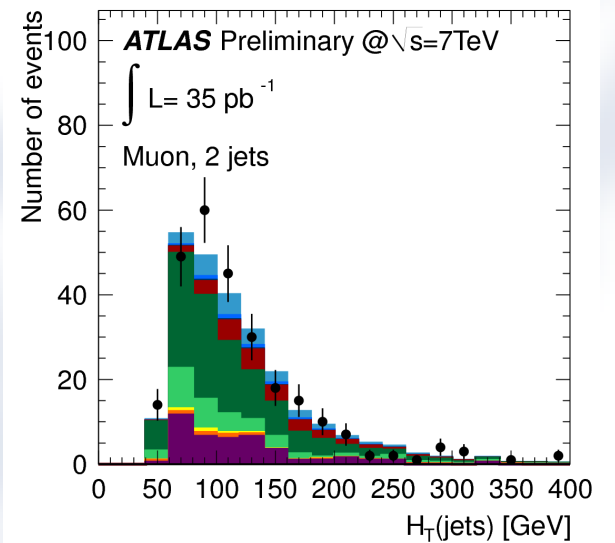
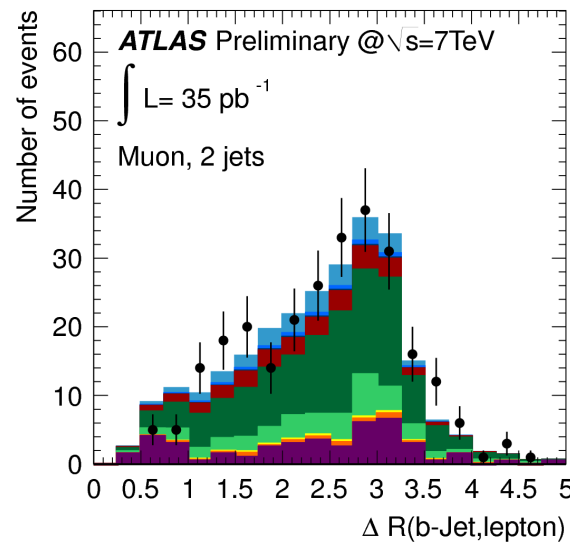
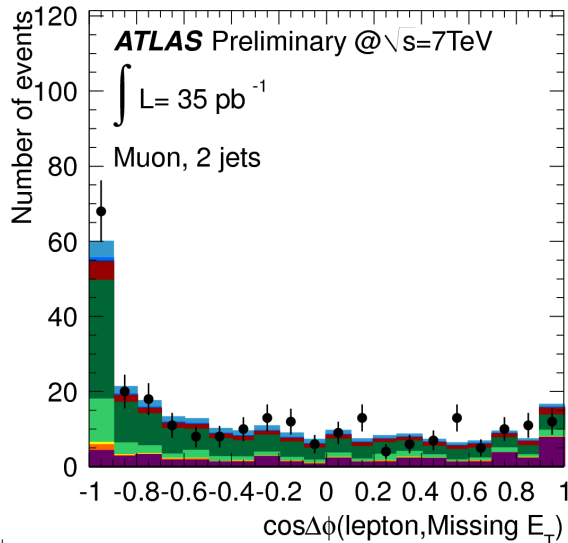
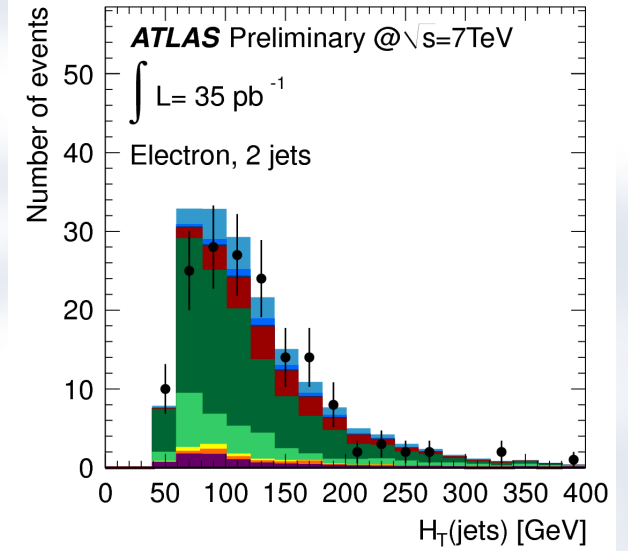
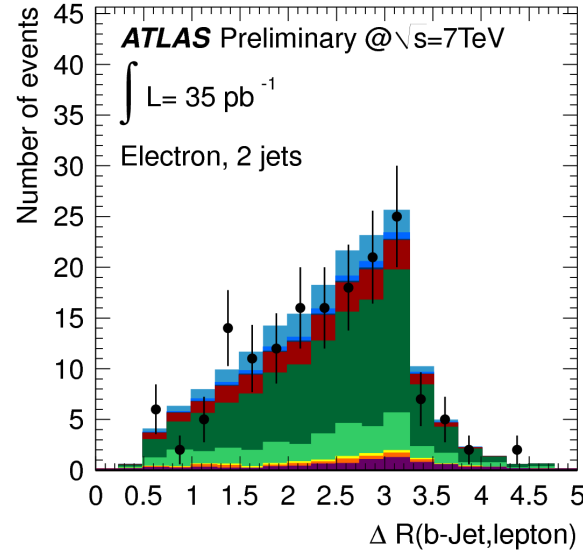
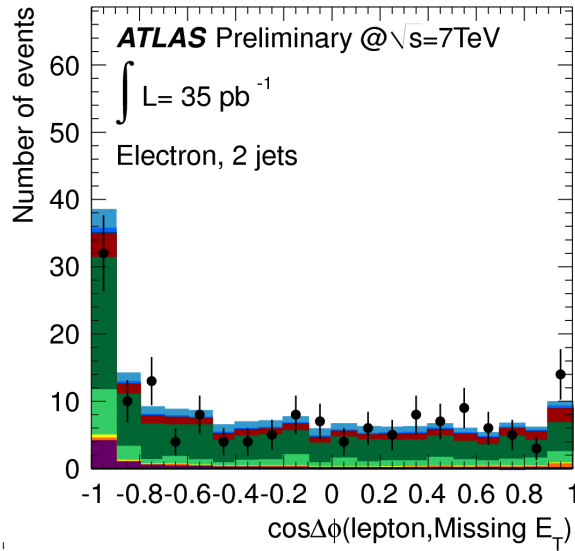
$$\begin{bmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{bmatrix} = \begin{bmatrix} rr & rf & fr & ff \\ r(1-r) & r(1-f) & f(1-r) & f(1-f) \\ (1-r)r & (1-r)f & (1-f)r & (1-f)f \\ (1-r)(1-r) & (1-r)(1-f) & (1-f)(1-r) & (1-f)(1-f) \end{bmatrix} \begin{bmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{bmatrix}$$

W+jets Background Estimation

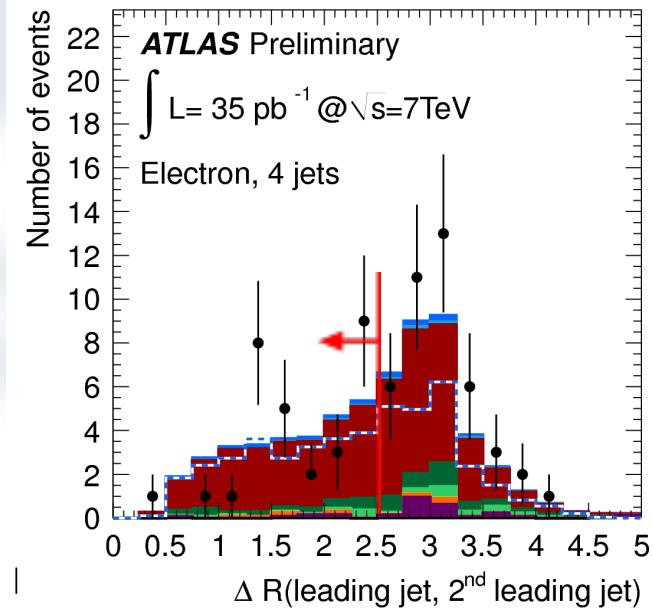
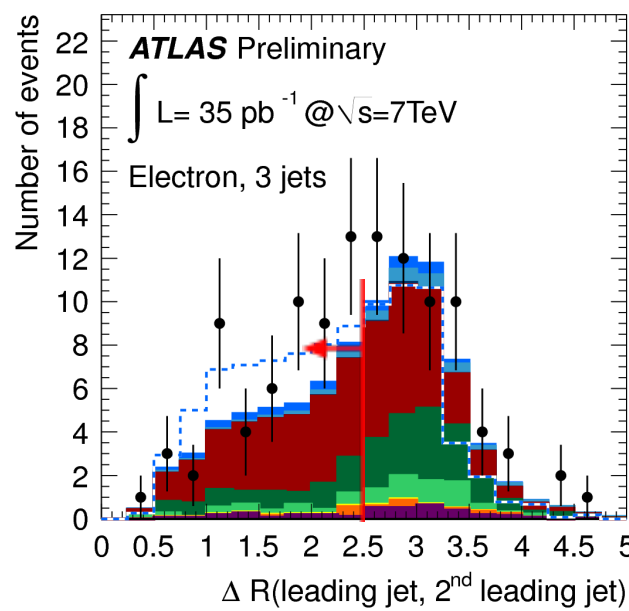
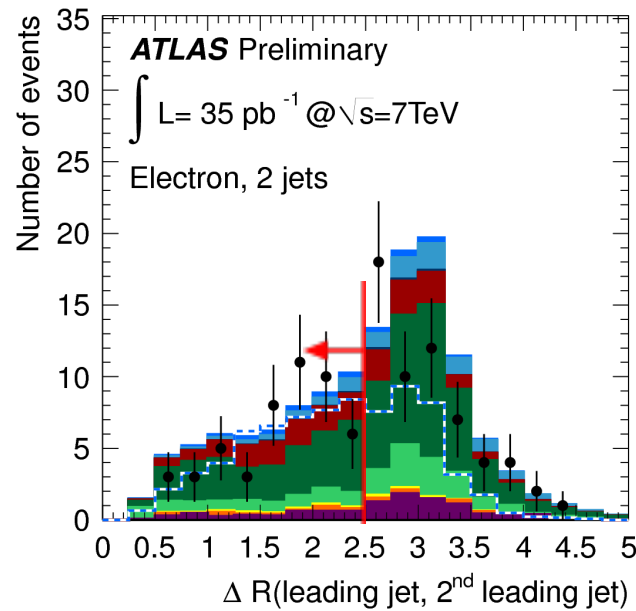
- Normalization in pretag sample obtained by event counting for each jet multiplicity
 - i.e. $N_W = N_{\text{Data}} - N_{\text{QCD}} - N_{\text{MC}}$
- Flavor composition obtained by tag counting
 - 3 unknowns: $f_{\text{light}}, f_c, f_b$
 - 3 control samples: 1-jet pretag, 1-jet tag, 2-jet pretag
- Results are combined into a single scale factor for each flavor/jet multiplicity

<i>K</i> factor	K_{bb}	K_{light}	K_c
W + 1jet	0.71±0.10(stat)±0.62(sys)	0.99±0.01(stat)±0.18(sys)	1.56±0.16(stat)±0.72(sys)
W + 2jet	0.68±0.09(stat)±0.64(sys)	0.95±0.02(stat)±0.25(sys)	1.50±0.16(stat)±0.66(sys)
W + 3jet	0.65±0.09(stat)±0.65(sys)	0.91±0.02(stat)±0.34(sys)	1.43±0.16(stat)±0.65(sys)
W + 4jet	0.65±0.09(stat)±0.76(sys)	0.90±0.04(stat)±0.53(sys)	1.43±0.17(stat)±0.78(sys)

t-channel Variables



Wt-channel l+j Electron Results



Electron	2 jets	3 jets	4 jets
Wt-channel	2.3 ± 0.5	2.7 ± 0.4	1.2 ± 0.2
Total expected	56.3 ± 12.9	40.0 ± 6.5	29.0 ± 3.5
Data	49	55	29
S/B	0.04	0.07	0.04

